Transparent Materials for Armor – A Cost Study

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Outline

- Background
- Current Demand Data
- Government Cost/Benefit Analysis
- Ballistic Depth of Penetration (DOP) Test
- Summary

Cost Study Beginnings

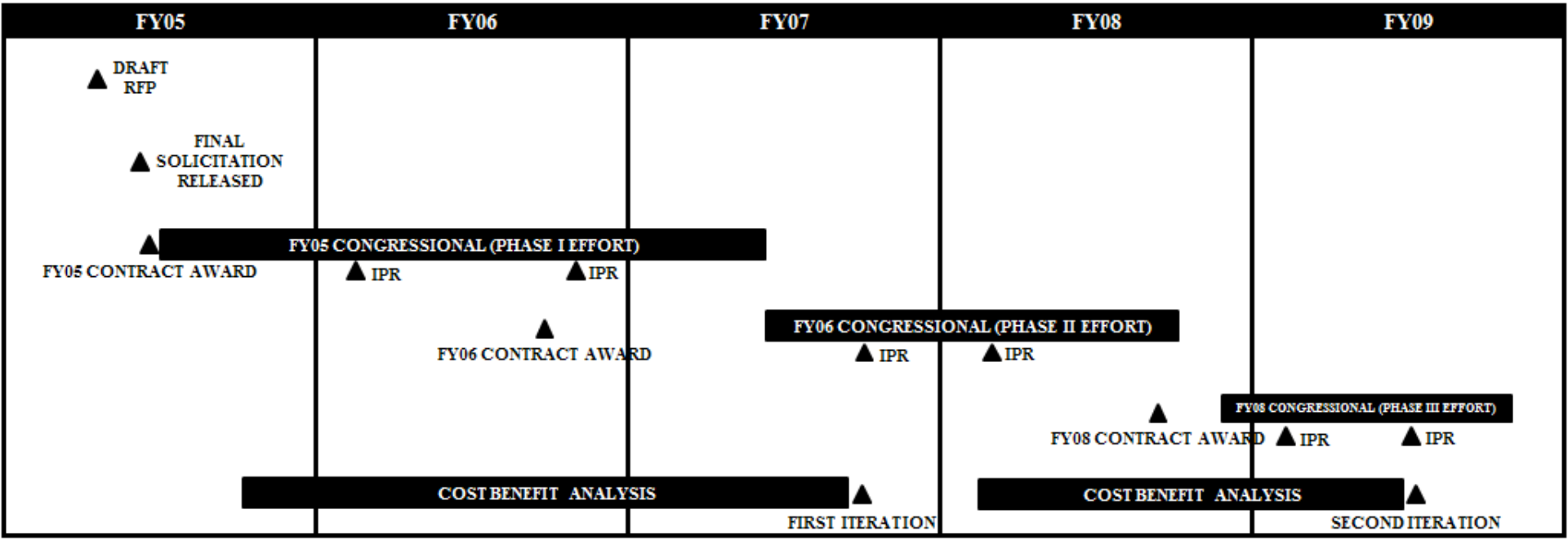
- Sagamore Army Materials Research Conference
  - Began in 1954, each conference focuses on a materials-related topic
  - Provides a forum for scientists and engineers from academia, industry, and the government to discuss a different topic each time and its importance to the Army and the greater DOD materials communities
  - Past themes include risk and failure analysis, residual stress and stress relaxation, corrosion prevention and control
  - http://ammtiac.alionscience.com/pdf/AMPQ9_2ART03.pdf
- Sagamore 2005 → *Transparent Materials*
  - Superior (new) materials for missile domes available for ~ 30 years, *but not used*
  - Once a material is in the "system", replacement or substitution generally absent
  - Cost not performance dominates material selection decisions
- Challenge: *Develop a tool for decision makers to find the break-even cost point for materials that improve performance*

Initial Research Project

- Develop strong and damage tolerant transparent ceramics* for use in high performance armor/window/dome systems
- Materials considered or in-use for transparent armor applications
  - Ballistic glass
  - Al_2O_3 (single crystal, Sapphire)
  - AlON (ALON)
  - $MgAl_2O_4$ (Spinel)
  - $Y_3Al_5O_{12}$ (YAG),
  - nanocrystalline Al_2O_3 (Alumina)
- Available "Commercial" Spinel
  - Non-optimal strength (avg <150 Mpa)
  - Large (>50 μm), bimodal grain structure

** With knowledge gained from 2005 Sagamore, this project appeared , although genuine and cutting edge, to be another "so what" exercise unless a concurrent cost study could be undertaken.*

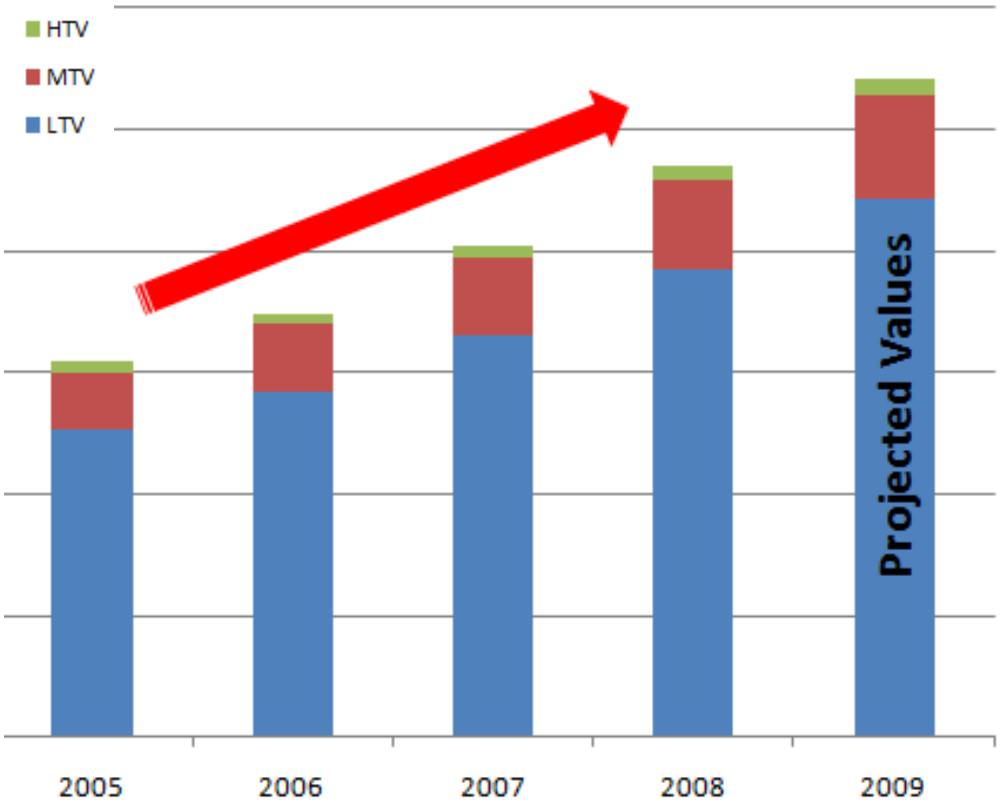
Timeframe for Research and Cost Study



Outline

- Current Demand Data

Equipping Our Soldiers in Iraq and Afghanistan



The size of the tactical fleet has been growing exponentially for the past 3 years.

The level of protection (transparent and opaque) continues to increase due to increased threats.

More vehicles = More glass

Example: M1114 Recent History

Early OIF

Curb Wt: 10,300lbs
GVW: 12,100lbs

More Vehicles
More Attacks
More Glass

2004-2005 GPK (Gunner Protection Kit)

2006 "Iraqi Pope Glass"

Future Transparent Gun Shields

Requirement:

Upgrade GPKs with transparent armor for enhanced situational awareness while maintaining soldier cover within armor envelope.

Baseline

AHI GS & GPK

Field Modified GS & APK

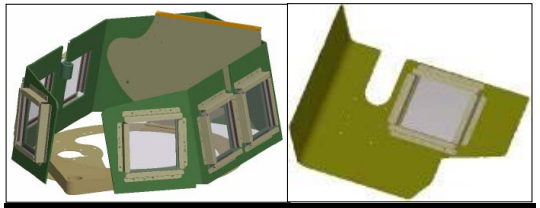
Interim

Interim Solution – Marine Corps TAGS (MCTAGS)

Initial

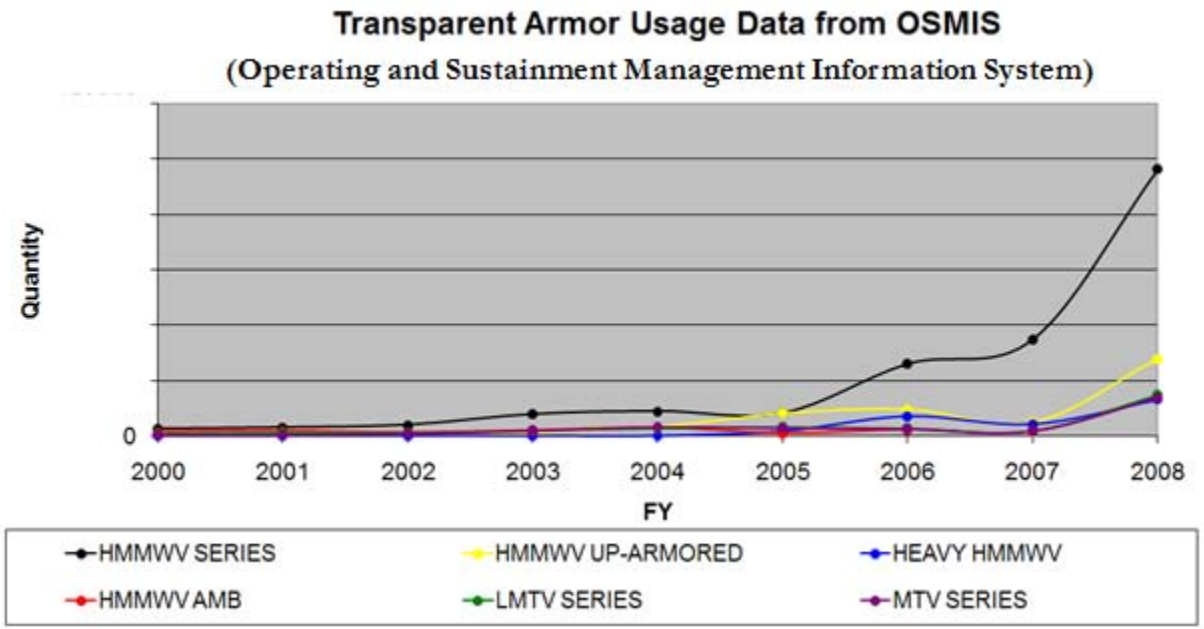
Upgraded Gunner Shield – Transparent Armored Gun Shield (TAGS)

Objective



Future Solution – Modified Solution based upon theater recommendations

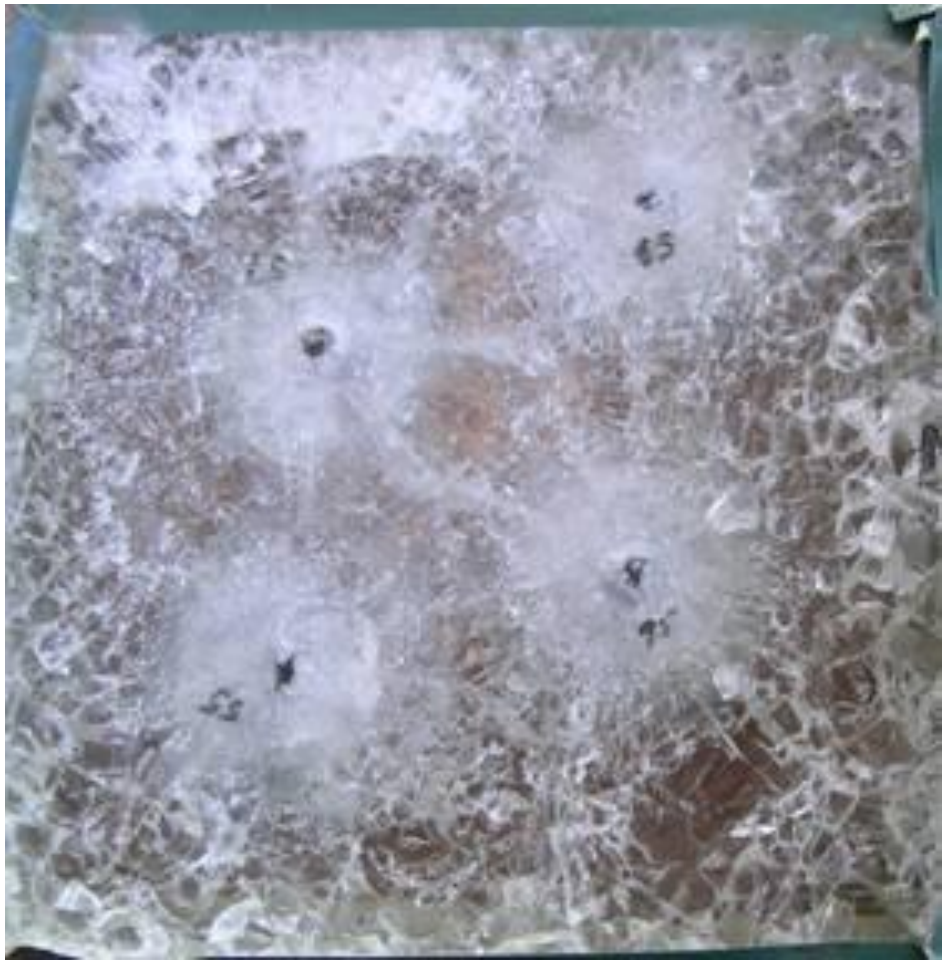
Tactical Vehicle Glass Demand



- **Average Total ($)** for transparent armor increased by about 20% (each year) from FY06-08.
- **Average Demand (qty)** for transparent armor increased by about 70% (each year) FY06-08.
- **$110,000 per day** was spent during FY06-08 for the **tactical fleet's** transparent armor.
- **Bottom Line***: Army needs an improved transparent armor solution!*

Causes of Current Glass Failure

- Insurgent Attacks – wide range of threats
- Sandstorm Damage
- Rock Strikes
- Improper removal/installation
- Clouding
  - Delamination from environmental degradation
  - Improper curing process
  - Improper cleaning



OIF Data Collection (Aug 2007)

- Each year, AMSAA (Army Materiel Systems Analysis Activity) collects detailed data on a specific set of vehicles by serial number.
- Data collectors embedded within units to collect various data elements
  - OPTEMPO
  - Part Replacements
- Requested glass data be collected over a 4-month period
  - Date of Incident
  - Vehicle Model
  - NSN
  - Serial Number
  - Location
  - Window Type
  - Failure Type
  - Remarks
- Provided pictures in some cases

AMSAA Sample Data Collection Effort

- 266 damage incidents
  - 115 M1114
  - 151 Other
    - 44 M1070
    - 44 M915A3
    - 63 Misc – ASV, M1130, Other HMMWV, FMTV, etc.
- 6 damage categories
  - Combat, Sand Storm, Rock Strikes, Clouding, Delamination, Installation

Pictures of Sample Vehicles

M1114 – Up-Armored HMMWV

M1070 – Heavy Equipment Transporter Tractor

M915A3 – Light Equipment Transporter

ASV – Armored Security Vehicle

M1130 – Stryker Commander's Vehicle

FMTV – (Light) Medium Tactical Vehicles

Analysis

Approaches with one categorical data set:

- Histogram of data set to visualize data
- Some statistical bounds on the average value of each category's expected value (%) based on sample size and the desired confidence

Average Category Value (%)	Sample		
Category	All	M1114	Other
COMBAT DAMAGE	62.8%	71.3%	56.3%
SAND STORM DAMAGE	0.0%	0.0%	0.0%
ROCK STRIKE	31.6%	25.2%	36.4%
IMPROPER INSTALLATION	0.0%	0.0%	0.0%
CLOUDING	3.4%	3.5%	3.3%
DELAMINATION	2.3%	0.0%	4.0%

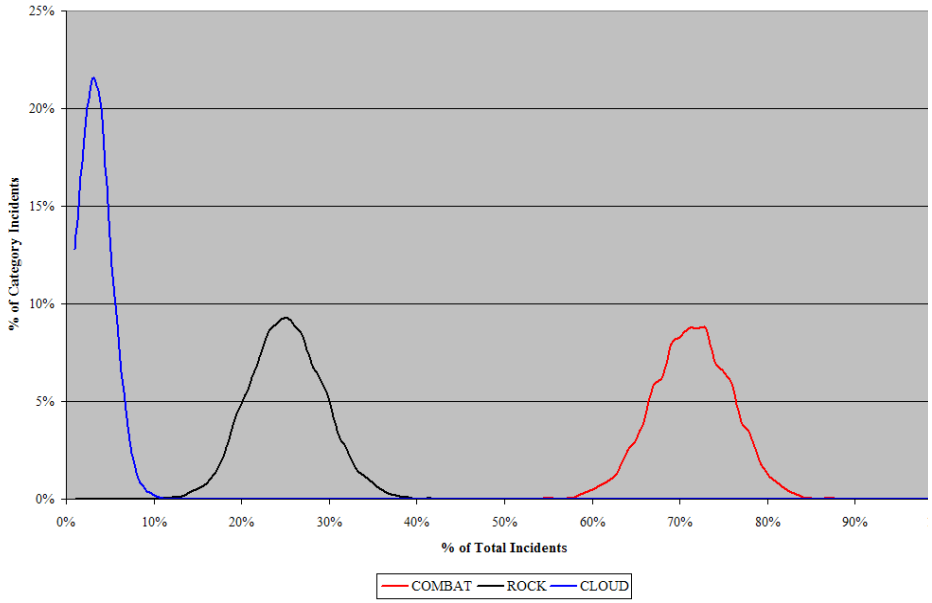
Bound on Average	Confidence Level		
Sample Size	90%	95%	99%
266 (All)	± 5%	± 6%	± 7.9%
115 (M1114)	± 7.7%	± 9.1%	± 12%
151 (Other)	± 6.7%	± 8%	± 10.5%

Other Analysis

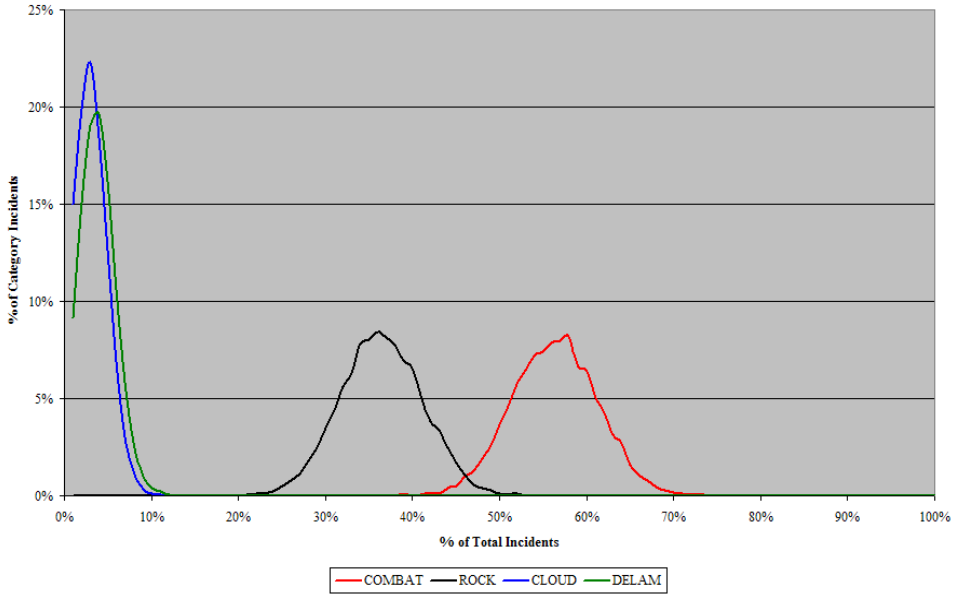
- One sample histogram data doesn't give a good visual picture or idea of what possible values could be.
- One way to get a distribution profile that models the sample data is to resample using the bootstrap technique.

Bootstrap Distribution

M114 Transparent Armor Damage Profiles



Other Variant Transparent Armor Damage Profiles



Problems with Current Glass Favoring a Ceramic Based Solution

- Current glass solution adds significant weight to vehicle
- Thickness of glass can cause distortion and glare

Future Transparent Armor Solutions

Cause of Failure	Potential for Improvement over Current Armor Solution
Insurgent Attacks	Depends on Threat
Sandstorm Damage	Yes
Rock Strikes	Yes
Improper removal and installation	Yes
Clouding	
- Delamination environmental degradation	Yes
- Improper curing process	Yes
- Improper cleaning techniques	Yes

Other Potential Benefits of a New Transparent Armor Solution

	Impact
Vehicle Weight	↓
Logistics Footprint	↓
Crew Survivability	↑
Operational Availability	↑
Safety Related Accidents	↓

Outline

- Government Cost/Benefit Analysis

Initial Cost-Benefit Study (2007)

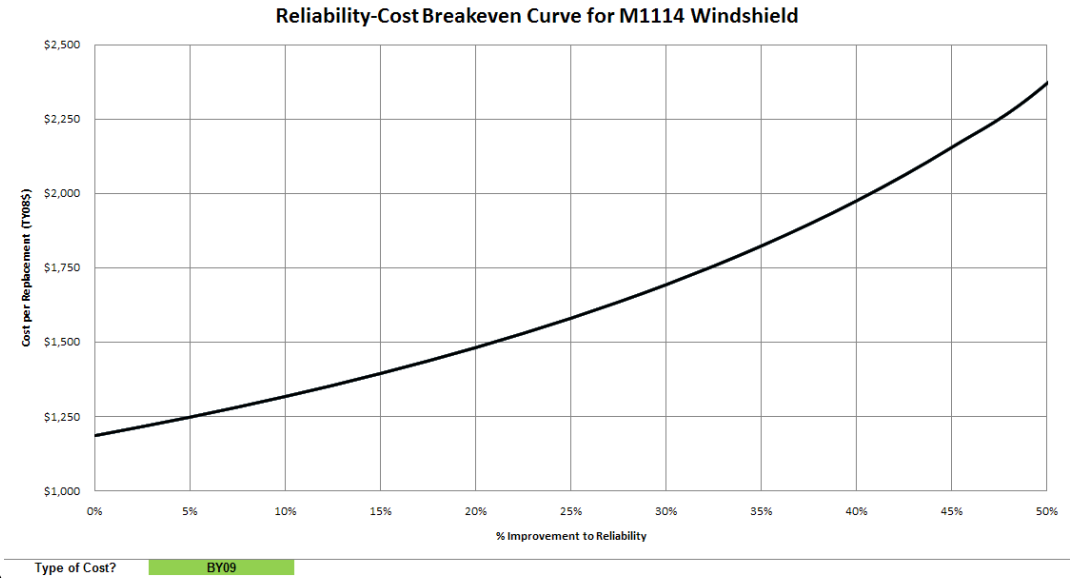
Purpose: Determine break-even cost for new transparent armor solution based on expected reliability improvement and required investment.

- Current fleet used as initial study platform (11,000+ vehicles)

- NSN 2510-01-435-9690/3 – L/R Windshield
  - $2,759 (FY06$)
  - $1,075 (FY09$)*
- NSN 2510-01-435-9692 – Door Window
  - $1,025 (FY06$)
  - $ 474 (FY09$)*

**Costs have decreased due to an increase in volume and the number of approved suppliers.*

Cost-Benefit Methodology

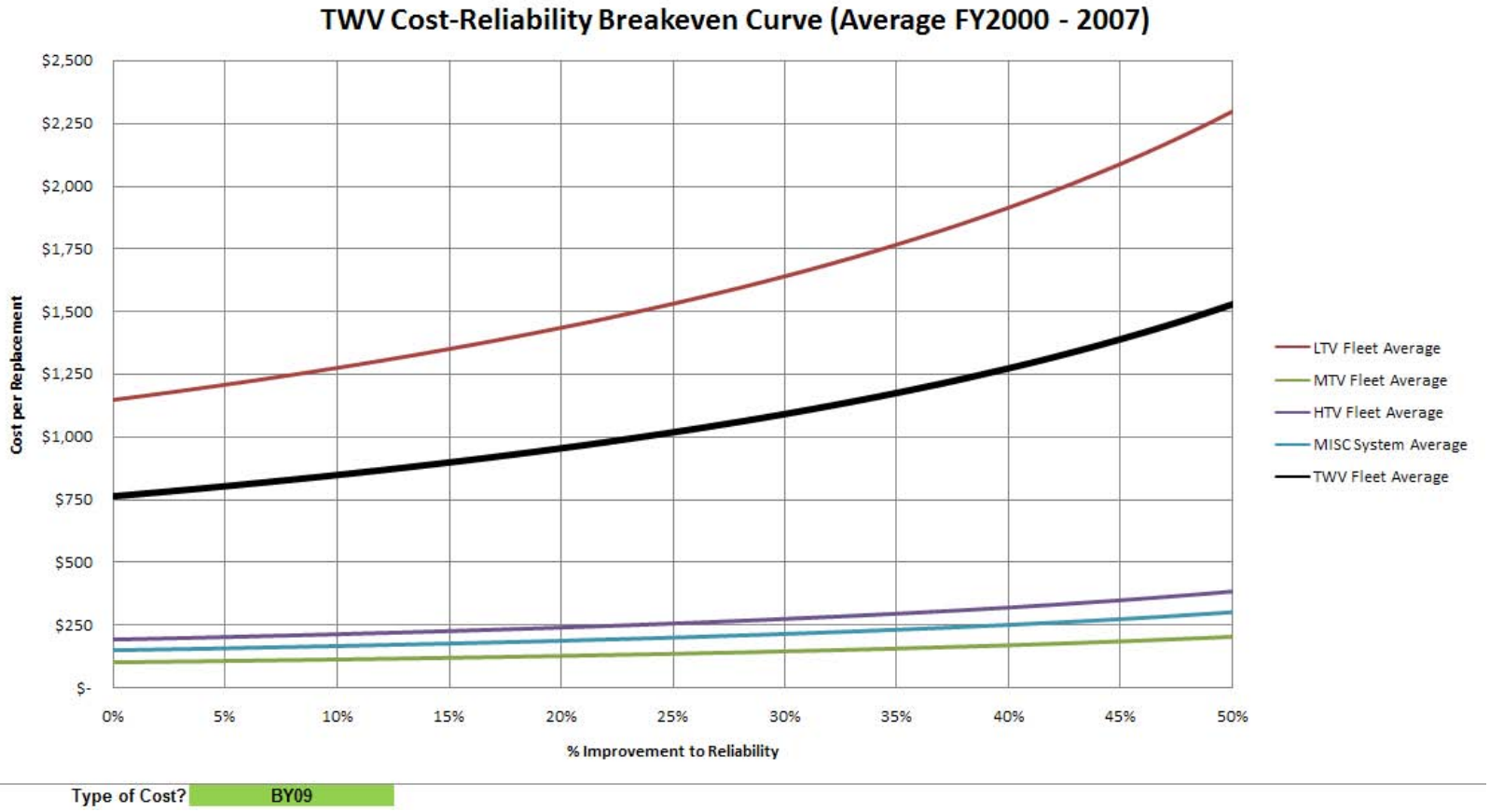


Parametric Analysis

- Obtain current demand data and cost data to determine operations cost for status quo.
- Obtain investment costs for new transparent armor solutions.
- Collect field data to determine distribution of failures.
- Determine improvement for new transparent armor solutions
- Determine break-even point on curves.

Curves based on 2007 demand data from initial study (Phase I).

Cost-Benefit Parametric Analysis: Expanded to Tactical Fleet Glass



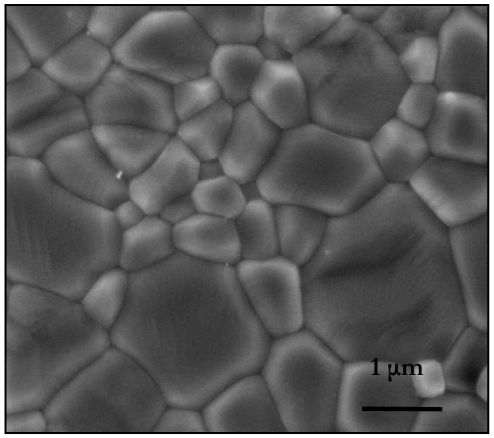
Outline

- Ballistic Depth of Penetration (DOP) Test

In 26 Months

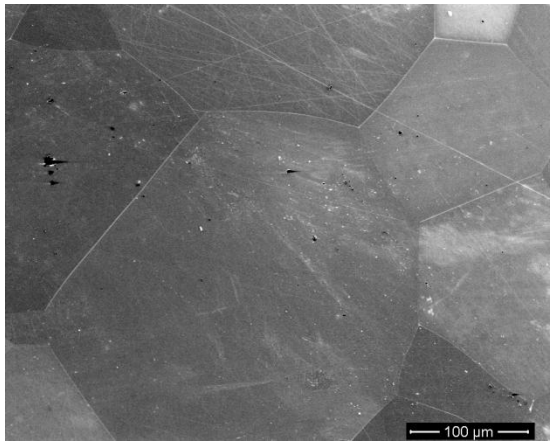
- Achieved* Nanostructured Spinel
  - average biaxial flexural strength > 480 MPa
  - grain size < 2 μm
  - > 80% in-line transmittance at 632 nm wavelength, 3/8" thick samples

Dry pressed, pressureless sintered + HIP'ed Spinel



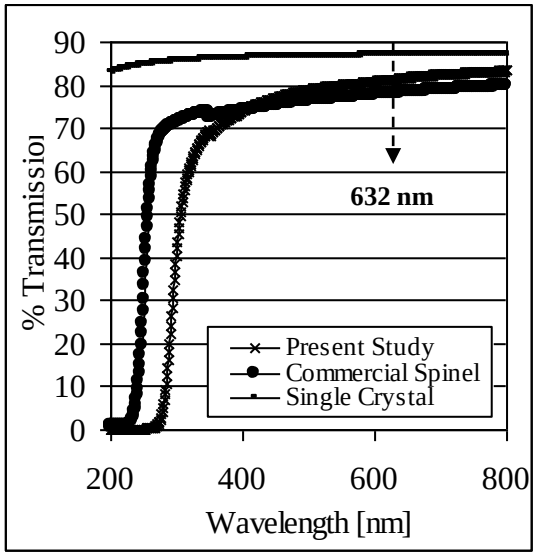
Average grain size ~1.4 μm

Commercially-available hot pressed + HIP'ed Spinel



Average grain size >50 μm

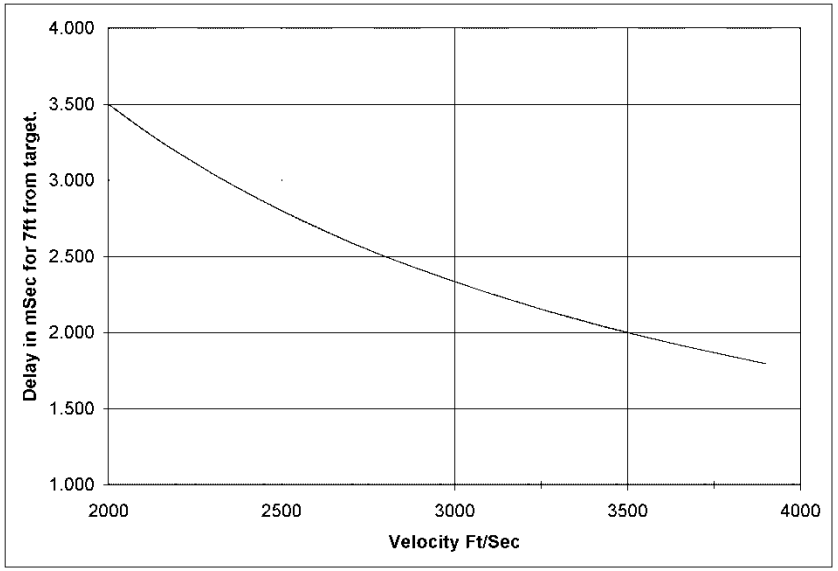
Specular transmission normalized to 9.6 mm thickness



*GE Global Research, TACOM Contract # W56HZV-05-C-0517, Sean Sweeney, April 2009

Initial Ballistic DOP* Test
3″ disks

Glass Baseline Ballistic Test



Spinel Comparison Ballistic Test –
to be continued

"Commercial"

Nanostructured

**TARDEC, Dr. David Nelson Hansen, Mr. Terry Avery, Mr. Matthew Magner*

Summary

- TARDEC and TACOM took up the challenge to develop a tool for decision makers to find the break-even cost for new materials that improve transparent armor performance
- The initial Cost-Benefit Methodology for the M114 (HMMWV) Windshield has been extended to the Tactical Fleet Glass
- A two-phase, 26 month basic research effort yielded a nanostructured, spinel with > 80% in-line transmittance in the visible range
- Ballistic DOP tests comparing commercially available large grained spinel with nanostructured spinel are in-process at TARDEC